Rec'd PCT/PTO 16 JUL 2003
10/069547

Description

TECHNICAL FIELD

This invention relates generally to a sensing method and apparatus, more specifically physical value sensor for use in an explosive atmosphere. A sensor is made of resistive or capacitive impedances related to physical value of the environment, i.e. pressure, temperature, flow et al. Since this kind of sensors is passive element electrically, that is to say, a sensor need be driven by an external power supply. And a sensor signal processor, which aims a protection concept, gets a signal response from a sensor that especially must be put in hazardous area.

BACKGROUND

A hazardous area is defined as an area in which explosive atmospheres, or may be expected to be, present in quantities such as to require special precaution for the construction and use of electrical equipment. Intrinsic safety is a protection concept employed in potentially explosive atmosphere. Intrinsic safety relies on the electrical apparatus being designed so that it is unable to release sufficient energy, by electrical means, to cause an ignition of a flammable gas. In electrical circuits the mechanisms for the release of this ignition energy are supposed as follows: Open circuit or Short circuit of components, Interconnection in a circuit and so on.

To realize intrinsic safety, a safety barrier may be designed in non-hazardous area by relatively large circuits with energy limiting resistors, zener diodes, fuses and so on. Then there were some problems that it is not clear to distinguish the true impedance of the sensor from current limiting impedances, and yet imprecise measurement is caused by the noise effects chiefly coming from temperature characteristics of those impedances.

And a technology to realize intrinsic safety by blocking capacitors has been tried in other technical field, of microwave band antenna's barrier invention (JP10-013130). The blocking capacitor is so known effective to take care of AC modulated signal since it blocks DC voltages. However, the sensor has been ordinarily driven by DC power in this field, which treats a small change of physical value, and it has been difficult to avoid its large conductance change noise.

Heretofore, it is easy and certain to install the safety zener barrier so as to cover a sensor device as a whole from the external layer a power supply belongs to. But such an instrumentation that requires an external barrier may be a big thing because of wiring cost and space factors for mounting.

SUMMARY OF THE INVENTION

In view of foregoing, it is an object of the present invention to provide a sensor signal processing circuit which itself contains a safety barrier that limits the current energy not to ignite an explosive environment where a sensor element exists, especially by making the safety barrier low cost and compact enough to be mounted in non-hazardous area or in an enclosure in hazardous area. This safety barrier allows for the sensor signal processing circuit that would otherwise not be able to achieve

intrinsic safe level approvals to attain such approvals standardized by official agencies.

Referring now to the drawings and in particular to FIG1, there shown is a diagram wherein only a sensor element exists in hazardous area. Also, referring to the drawing FIG.2, there shown is a diagram wherein a sensor element exists in hazardous area and a transmitter including a safety barrier exists in an enclosure in hazardous area. In both cases shown is a conceptual diagram that a sensor element has no power, essentially to realize intrinsic safety.

FIG.3 shows a prior art where resistors (Rh) limit the current in the event of said cases. Assuming that maximum voltage up to 250V(DC or AC commercial power supply) was charged, current limiting resistors works to decrease the rush current into hazardous area. This voltage may be suppressed by a zener diode (out of drawing), or only current may be limited to suppress the rush energy. The current value is normally calculated as EQU (1) because of the Thevenin's theorem with not only the sensor impedance (ZS) but also current limiting resistors (Rh). The measured ampere I is considerably affected by a temperature characteristic of Rh in this case.

$$I = \frac{Vin}{ZS + 2 \cdot Rh} \quad \cdots (1)$$

Now there are two approaches greatly to solve an applied subject. First approach is, like FIG.4, to equip two OP amps, the driver and the feeder, between the sensor terminal and the signal line to the processing unit, so that current resistors' impedance can be ignored, provided that OP amp must be ideal enough to regard Op amp's open gain Av as infinite large, input impedance as infinite large and output impedance as zero. (OP amp's characteristics are ideal in the below description.) As a result, the normal sensor's voltage at the sensor terminal A and B could be EQU (2) and (3).

$$Va = Vin \quad \cdots (2)$$
$$Vb = 0 \quad \cdots (3)$$

Therefore the ampere I measured by the ampere meter (A) is as EQU (4). The sensor impedance (ZS) that leads to physical value is calculated from EQU (4) without any affection of impedance Rh.

$$I = \frac{Vin}{ZS} \quad \cdots (4)$$

Next, second approach is, like FIG.5, to realize the current limiting without having a large resistance. There the driving force (Vin) may be

AC by higher frequency than supplied power frequencies 50/60Hz, and the blocking capacitors are mounted. These capacitors' impedance may be anti-proportional to a supplied frequency, so it is possible for the blocking capacitors' impedance to be low enough to ignore in a normal mode and to be large enough to limit the current through the sensor. The measured current normally is in FIG.5 as EQU (5) according to the Thevenin's theorem.

$$I = \frac{1}{ZS + \dfrac{2 \cdot Rh}{1 + \dfrac{1}{3} \cdot j \cdot \omega \cdot Ch \cdot Rh}} \cdot Vin \quad \cdots (5)$$

Now providing the normal measuring frequency $\omega (=2\pi f)$ is made much higher than 1kHz and relatively larger than Ch or Rh, the second item of the divisor can be neglected as EQU (6).

$$I = \frac{Vin}{ZS} \quad \cdots (6)$$

In summary, this sensor signal processing circuit provides a solution to realize intrinsic safety with a precise measurement, by means of sensor driving with the driver and the feeder OP amps and by means of blocking capacitors impedance negligible at high frequency zone.

The above and further objects and novel features of the invention will more fully appear from the following details description when the same is read in connection with the accompanying drawings.
It is to be expressly understood, however, that the drawing is for the purpose of illustration only and is not intended as a definition of the limits of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram wherein only a sensor element exists in hazardous area.

FIG. 2 is a block diagram wherein a sensor element exists in hazardous area and a transmitter including a safety barrier exists in an enclosure in hazardous area.

FIG. 3 is a PRIOR ART of an intrinsic safety schematic by current limiting resistors (Rh).

In the below accompanying drawings, non-hazardous area is regarded as including the inside of an enclosure in hazardous area.

FIG.4 illustrate a first embodiment of the present invention with current limiting resistors (Rh) and OP amps to get a sensor signal as current value.

FIG.5 illustrates a second embodiment of the present invention with blocking capacitors (Ch) without OP amp.

FIG.6 illustrates a third embodiment of the present invention with blocking capacitors (Ch) and OP amps to get a sensor signal as current value.

FIG.7 illustrates a fourth embodiment of the present invention as improved from a first embodiment (FIG.4), to get a sensor signal as voltage value.

FIG.8 illustrates a fifth embodiment of the present invention as improved from a third embodiment (FIG.6), to get a sensor signal as voltage value.

Reference Numerals and symbols

1	Sensor Element
2	A whole Transmitter except a sensor
3	Safety Barrier
4	Processing Unit
5	Receiver
6	Power Supply for commercial, industrial use et al
7a	Sensor Driving Power (DC)
7b	Sensor Driving Power (AC)
10	The Driver OP amp
20	The Feeder OP amp
30	Ampere Meter
31	Voltage Meter
100	Reference Resistor
Rh	Current Limiting Resistor
Ch	Blocking Capacitor
Vin	Voltage of 7a or 7b
ZS	Sensor Impedance
FG	Frame Ground
Vcc	Power Supply to OP amps

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Preferred embodiments of the present invention are described in more detail below referring to the accompanying drawings.

(1) First embodiment of the present invention

FIG.4 shows the sensor signal processing circuit relating said first approach of the summary. The driver OP amp (10), as an output

buffer, drives the supplied voltage (Vin 7a) toward the sensor (1). The feeder OP amp (20) measures the feedback current passed through from the sensor. As a result of EQU (4), sensor's impedance (ZS) can be got from the given Vin and the measured ampere I be got by meter (A). The physical value is sought via various scientific calculations additionally.

Assuming that all other components except current limiting resistors (Rh) broke and each Rh was charged by the voltage 250V, the number of rush current path to hazardous area may be four. It is required to limit the current from any of four Rh throughout the sensor toward the ground (FG) to 10mA that could cause an explosion, for instance of a safety Class requirement. Four Rh may be more than 100KΩ to limit the current from every Rh to below 2.5mA. This instance is common in the further embodiments.

(2) Second embodiment of the present invention

FIG.5 shows the sensor signal processing circuit relating said second approach of the summary. By the effect of blocking capacitors (Ch), the current through the sensor (1) is normally operated as EQU (6), and it can be limited as small as EQU (5) even though the power voltage is charged onto the driving voltage (Vin). Yet the blocking capacitors (Ch) may be on two stacks or more in series to meet the intrinsic safety regulations. Here are the resistors (Rh) added for current limiting and DC bias use.

Assuming that all of the resistors (Rh) and the blocking capacitors (Ch) were charged by the voltage 250V, it is required to limit the current from those elements throughout the sensor toward the ground (FG) to 10mA. The number of current path is four same. So two resistors (Rh) may be more than 100KΩ to limit the current to 2.5mA and at least one surviving capacitor (Ch) on the current path may be less than 26nF to limit the current to 2.5mA which is calculated as the multiplier of $2\pi f^{*}Ch$ and 250V for instance. (Here, $\omega = 2\pi f$, and f may be a commercial frequency 60Hz.)

(3) Third embodiment of the present invention

FIG.6 shows the sensor signal processing circuit relating the combination of said first and second approach of the summary. This makes the blocking capacitors (Ch) negligible by making the OP amp regardless of the frequency of ω. The measure by this embodiment is as following EQU (7) because it is based on the same theory from EQU (2) and (3). OP amps are ideal as same as before.

$$I = \frac{Vin}{ZS} \quad \cdots (7)$$

The driver (10) and the feeder (20) have respectively the current limiting resistors (Rh) and the blocking capacitors (Ch) on all lines towards the sensor.

Assuming that all other components except current limiting resistors (Rh) or blocking capacitors (Ch) broke and each Rh and Ch was

charged by the voltage 250V, the number of current path may be eight. It is required to limit the current throughout the sensor toward the ground (FG) to 10 mA. Four Rh may be more than 200KΩ to limit the current from every Rh to 1.25mA and every Ch may be less than 13nF similarly as before instance.

(4) Fourth embodiment of the present invention

In the above embodiments, specifically the first embodiment, current meter achieves the measurement. However, the current measurement is not practical for further circuitry, compared to the voltage measurement. And it is not favorable to measure simply the output of the feeder OP amp in FIG.4 because of the dependency of the precision of current limiting resistor (Rh) as EQU (8) as follows.

$$V = -\frac{Rh}{ZS} \cdot Vin \quad \cdots (8)$$

Therefore the improvement of the first embodiment of the invention is preferred as FIG.7, to set the reference resistor (ZREF 100) for constructing a negative feedback. The output of OP amp (20) can be obtained as EQU (9) with no Rh factor, so the sensor impedance (ZS) can be calculated precisely.

$$V = -\frac{ZREF}{ZS} \cdot Vin \quad \cdots (9)$$

The points to be charged by high voltage in the accidental case are outputs and inputs of OP amps (10) and (20) from which current limiting resistors are coupled to the sensor. Assuming that all other components except current limiting resistors (Rh) broke and each Rh was charged by the voltage 250V, the number of current path may be five. It is required to limit the current throughout the sensor toward the ground (FG) to 10 mA. Five Rh may be more than 125KΩ to limit the current from every Rh to 2mA for instance.

Furthermore the reference resistor (ZREF) has nothing to do with intrinsic safety and may have almost same value as the sensor (This is common in the next fifth embodiment). It may be a capacitive element instead of resistors.

(5) Fifth embodiment of the present invention

In the above third embodiment, the measurement is achieved by current meter, and it is not favorable to measure simply the output of the feeder OP amp in FIG.6 because of the dependency of the precision of resistors (Rh), capacitors (Ch) and sensor (ZS) impedances as EQU (10) as follows.

$$V = -\frac{Rh}{ZS \cdot (1 + \frac{1}{3} \cdot j \cdot \omega \cdot Ch \cdot Rh)} \cdot Vin \quad \cdots (10)$$

This does not provide the precise measurement of ZS, since output V contains Rh and Ch factors. Therefore the improvement of the third

embodiment of the invention is preferred as FIG.8, to set the reference resistor (ZREF 100) for constructing a negative feedback. The output of OP amp (20) can be obtained as EQU (11) without Rh or Ch factors, so the sensor impedance (ZS) can be calculated precisely.

$$V = -\frac{ZREF}{ZS} \cdot Vin \quad \cdots (11)$$

Same as the fourth embodiment, current limiting resistor (Rh), blocking capacitors (Ch) are set between the outputs of OP amp (10) and (20) and sensor (1) for intrinsic safety. . Assuming that all other components except current limiting resistors (Rh) or blocking capacitors (Ch) broke and each Rh and Ch was charged by the voltage 250V, the number of current path may be ten. It is required to limit the current throughout the sensor toward the ground (FG) to 10mA. Five Rh may be more than 250KΩ to limit the current from every Rh to 1mA, and every Ch may be less than 10nF similarly, for instance.

Additionally, the above noted parameters of Rh and Ch do not limit this invention.

Furthermore, the included safety barrier in the circuit can be applied in plants, manufacturing processes or laboratories in especially dangerous environments (e.g., gaseous, ignitable, etc.).